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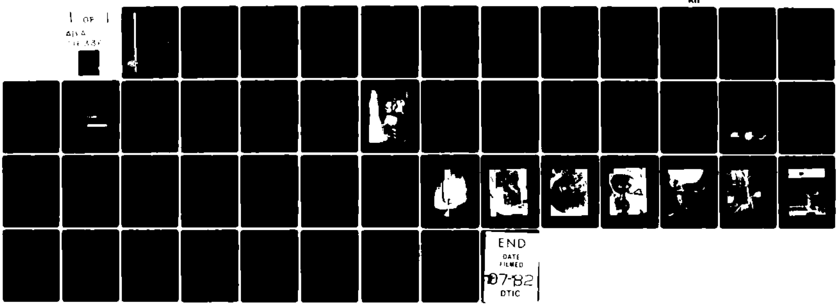

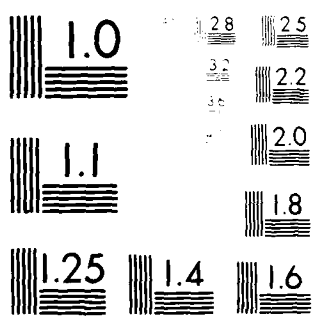

MICROCOPY RESOLUTION TEST CHART

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Report 2353

NEW APPROACH FOR REPLACING BRAKE FLUID IN MILITARY VEHICLES

by
Charles C. Chapin
James H. Conley
and
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March 1982

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U.S. ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT COMMAND
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A new method for converting military vehicles to silicone brake fluid has been developed. This method involves the use of an intermediate fluid to bring about a density inversion so that when the silicone brake fluid is added to the system, the polyglycol/solvent (2-Ethyl hexanol; 2-EH) layer is displaced by the silicone fluid. The method has been tested in laboratory experiments as well as in several different types of vehicles.

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The use of this method, which is very effective at polyglycol removal, can be expected to increase the drop in maintenance costs (primarily due to component corrosion). In addition, the fluid remaining in the system after conversion has a very high vapor lock temperature and is functional at low temperatures.

PREFACE

The 310th Theatre Army Area Command Group cooperated and assisted MERADCOM by providing the 2½-ton test vehicles promptly.

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NEW APPROACH FOR REPLACING BRAKE FLUID IN MILITARY VEHICLES

I. INTRODUCTION

The U.S. Army has been using three different automotive hydraulic brake fluids covered by Federal Specification VV-B-680 for use in all Tank-Automotive Equipment (temperate-tropical areas), Military Specification MIL-H-13910 for arctic use, and Military Specification MIL-P-46046 for preservative use.[1] These polyglycol and castor oil type fluids are hygroscopic and absorb water while in use which adversely affects their performance by lowering the vapor lock temperature, by increasing the low temperature viscosity, and by contributing to component corrosion. A sludge is produced as a result of this corrosion, which can lead to cup scoring with subsequent fluid leakage and wheel cylinder failure.

In 1967, the U.S. Army began the development of a single multipurpose silicone-based brake fluid which would overcome the absorption of water exhibited by the conventional polyglycol fluids as well as provide all-weather and preservative properties. Thus, this one fluid, which replaces the three existing fluids can reduce logistics and maintenance costs. Any vehicle using this fluid will be ready for use in any geographical area, at a moment's notice. Thus, vehicles could be moved from the tropics to the arctic or could be put into storage without requiring any other (current) brake system maintenance procedures.[2]

Brake Fluid, Silicone (BFS) Military Specification (MIL-B-46176), which was developed by MERADCOM[3] in conjunction with industry, was approved for Army use, in 1980. All tactical vehicles, administrative use vehicles, commercially procured vehicles, construction equipment, and material-handling equipment which currently use polyglycol-type fluids will be converted to BFS. This conversion began in July 1981.

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[1]Federal Specification VV-B-680, *Brake Fluid, Automotive*, 20 July 72; Military Specification MIL-H-13910, *Hydraulic Fluid, Polar Type, Automotive, All Weather*. 3 Feb 67; Military Specification MIL-P-46046, *Preservative Fluid, Automotive Brake System and Components*, 26 Aug 64.

[2]Conley, J. H. and Jamison, R. A., *Army Experience with Silicone Brake Fluids*, S.A.E. Technical Paper Series No. 780660, 1978.

[3]MIL-B-46176, *Brake Fluid, Silicone, Automotive, All Weather, Operational and Preservative*, 27 Mar 78.

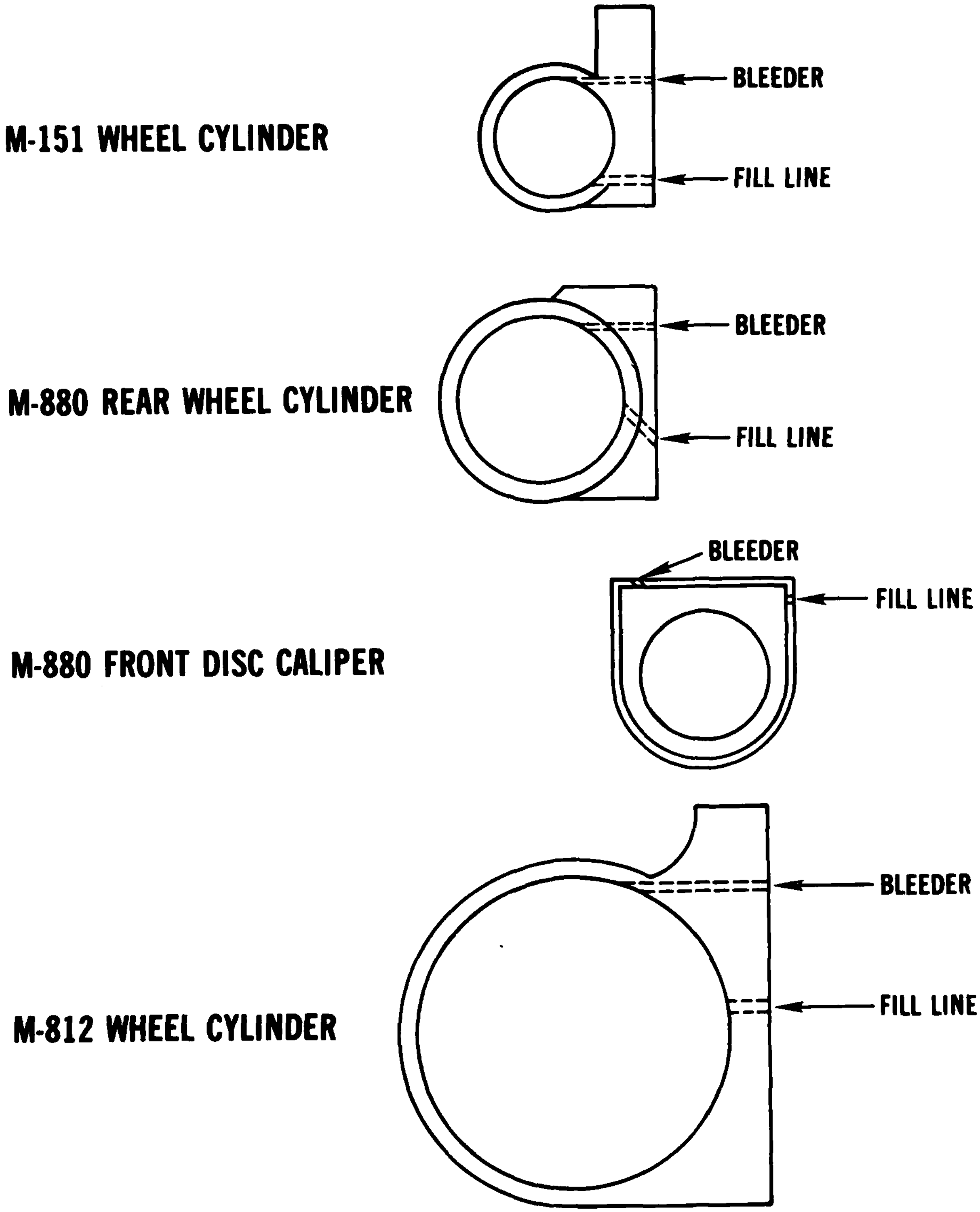

Figure 1. Cross-Sectional Diagrams of Wheel Cylinders Showing Location of Line and Bleeder Holes .

The wipe and clean procedure (Appendix A) for conversion, which was successfully tested at Yuma Proving Grounds, Arctic Field Test Center, and Panama Tropic Test Center[4, 5] and was the recommended conversion method, was found to be unacceptable due to the labor intensiveness of the procedure, its implications to manpower requirements, and cost.

An alternate method[6] for this brake fluid replacement, flush, and fill (TB43-0002-87) was considered to be a viable method based on these same considerations. A straight flush and fill method was tested by MERADCOM[7] and found to be inefficient. This was due to the following interdependent reasons:

a. The geometry of the wheel cylinders (with the bleeder valves at top).

b. The immiscibility of two types of fluids.

c. The lower density of the silicone relative to the current polyglycol fluid).

Figure 1 shows a cross section of each of the wheel cylinders and a caliper. The inlet lines and bleeder valves are indicated. The bleeder valves are always positioned at the uppermost point in the wheel cylinder to allow the lower density air to be bled from the system (the air rises to the top and out of the valve).

When a brake system containing polyglycol fluids is flush-filled with the silicone fluid, the silicone does not displace the fluid at the bottom of the wheel cylinders and calipers. The net result is that the silicone fluid overlayers the polyglycol fluid giving a liquid binary phase system. The two fluids do form a semi-stable emulsion but there is not sufficient turbulence under these conditions at the bottom of the cylinders for emulsion formation to take place.

This project was initiated for the purpose of addressing the problem of incomplete replacement of glycol fluid by the new silicone fluid in automotive hydraulic brake systems. The primary objective was to develop a method which would effect total polyglycol removal so that a greater degree of the benefits of the new fluid could be obtained. This method could potentially be used by maintenance personnel Army-wide. It must then be as simple as possible and should not deviate greatly from established brake-bleeding procedures.

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[4] Conley, J. H., and Jamison, R., *Silicone Brake Fluids: One Year Field Test*, MERADCOM Report No. 2132, February 1975.

[5] Conley, J. H., Jamison, R. and Jordan, C. B. *Silicone Brake Fluids: Two Year Field Test*, MERADCOM Report No. 2169, January 1976.

[6] TB43-0002-87, DA Technical Bulletin, *Brake Fluid, Silicone (BFS) Conversion Procedures for Tank-Automotive Equipment*.

[7] MERADCOM Letter Report, *Evaluation of Flush-Fill Procedures for Silicone Brake Fluid (BFS) Retrofit*, DRDME-GL, 6 Oct 80.

II. APPROACH

The approach used in this study was the use of an intermediate solvent to assist in the removal of the polyglycol. Such a solvent would need to be a cosolvent for silicones and polyglycols, must be inexpensive, must have a low freezing point, must have a high boiling point, and must be non-toxic and not hygroscopic. In addition, the intermediate fluid should preferentially dissolve the polyglycol in a system consisting of all three fluids (which is the case when the silicone is being added to the system). This phase behavior for the multicomponent system would be satisfied by a cosolvent which preferred the polyglycol. Solvents for silicones were then screened for use and evaluated against other physical properties (boiling point, toxicity, etc.).

The identification of the system during the conversion process as being a multicomponent binary phase system led to the possibility of making use of a property of some of these systems that is the possible existence of an isopycnic or twin density tie line.[8, 9] This approach would be made feasible by the selection of an appropriate intermediate solvent which would induce a reversal of the phases so that the polyglycol would then float on the silicone instead of the silicone floating on the glycol. This intermediate fluid (in this case 2-ethyl hexanol (2-EH)) was screened with respect to the other properties and by its density relative to the silicones and glycols. (Appendix B gives the properties for 2-EH.) Many fluids were screened but no other fluid was found which was superior to the 2-EH with respect to all of the concerns.

III. DESCRIPTION OF TESTS

1. **Air Flushing.** The following procedure was performed.

a. Apparatus. A wheel cylinder from a 5-ton truck with a spring, cups, and pistons was mounted in a vise and copper tubing was connected from the inlet to a syringe which had a three-way valve connected to it. The syringe allowed filling of the wheel cylinder from a reservoir. A vent tube was attached to the bleeder valve of the wheel cylinder and directed to the drain.

b. Experimental. This system was used to assess the utility of air flushing for polyglycol removal. Water was used, initially, to check for leaks in the system.

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[8]Francis, A. W., *Isopycnics and Twin Density Lines*, Ind. Eng. Chem., 48, 12,2789, 1953.

[9]Francis A. W., *Insolubilities of Inorganic and Organic Compounds*, A. Seidell and W. Linke, eds., Suppl. to 3rd ed., New York, P. Van Nostrand, ed., 1952.

2. **Solvent Addition.**

a. Experimental. A solvent known to be miscible with silicones was selected (2-ethyl hexanol, 2-EH) and 1 ml was added to 1 ml of a polyglycol brake fluid. The two were miscible. To this mixture, after shaking, was added 1 ml of BFS. The BFS went to the bottom of the test tube and retained its color. Upon vigorous shaking,the mixture was found to form an emulsion which settled after about 20 min into two distinct layers. The top layer was not transparent (a possible micro-emulsion) but, after sitting overnight, it was clear. Gas chromatographic analysis (Appendix C) of the layers revealed that the bulk of the polyglycol and solvent were in the yellowish upper phase, and that a small portion was in the lower clear phase (the dye from the BFS went into the polyglycol/2-EH layer). The 2-EH was tested and found to dissolve the silicone brake fluid (Figure 2).

b. The Phase Inversion Phenomenon (Figure 2). A = polyglycol fluid; B = silicone fluid; C = polyglycol after addition of silicone; D = 2-Ethyl Hexanol (2-EH); E = after mixing polyglycol with 2-EH and then adding silicone brake fluid. E is a multicomponent binary phase system which for the purposes of this study is treated as a ternary system consisting of (1) polyglycol; (2) 2-EH; (3) BFS. It sometimes happens that a tie line exists in these systems for which the densities of the two phases are equal. One author[10] makes the distinction between multicomponent and ternary component systems in his definition of this tie line because in the case of the multicomponent system this tie line is not a straight line, whereas in the ternary systems, it is. He calls the tie line an isopycnic tie line for a ternary system and a twin density tie line for multicomponent systems. For the purposes of this study, the exact position or the shape of this twin density tie line is not important, only that it exists (that a solvent can be found which generates a twin density tie line) for this system and that it can be passed (by adding 2-EH to the system). Once the polyglycol is diluted past the twin density tie line, addition of BFS to the system results in two phases, or if a sufficient amount of polyglycol has been removed, a single phase. Since the 2-EH is a solvent for the silicone (but is less dense), it will either simply go out the bleeder or dissolve and be available for flushing out of the system by dilution. E represents flushing by displacement.

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[10] Francis A. W., *Isopycnics and Twin Density Lines*, Ind. Eng. Chem., 48, 12, 2789, 1953.

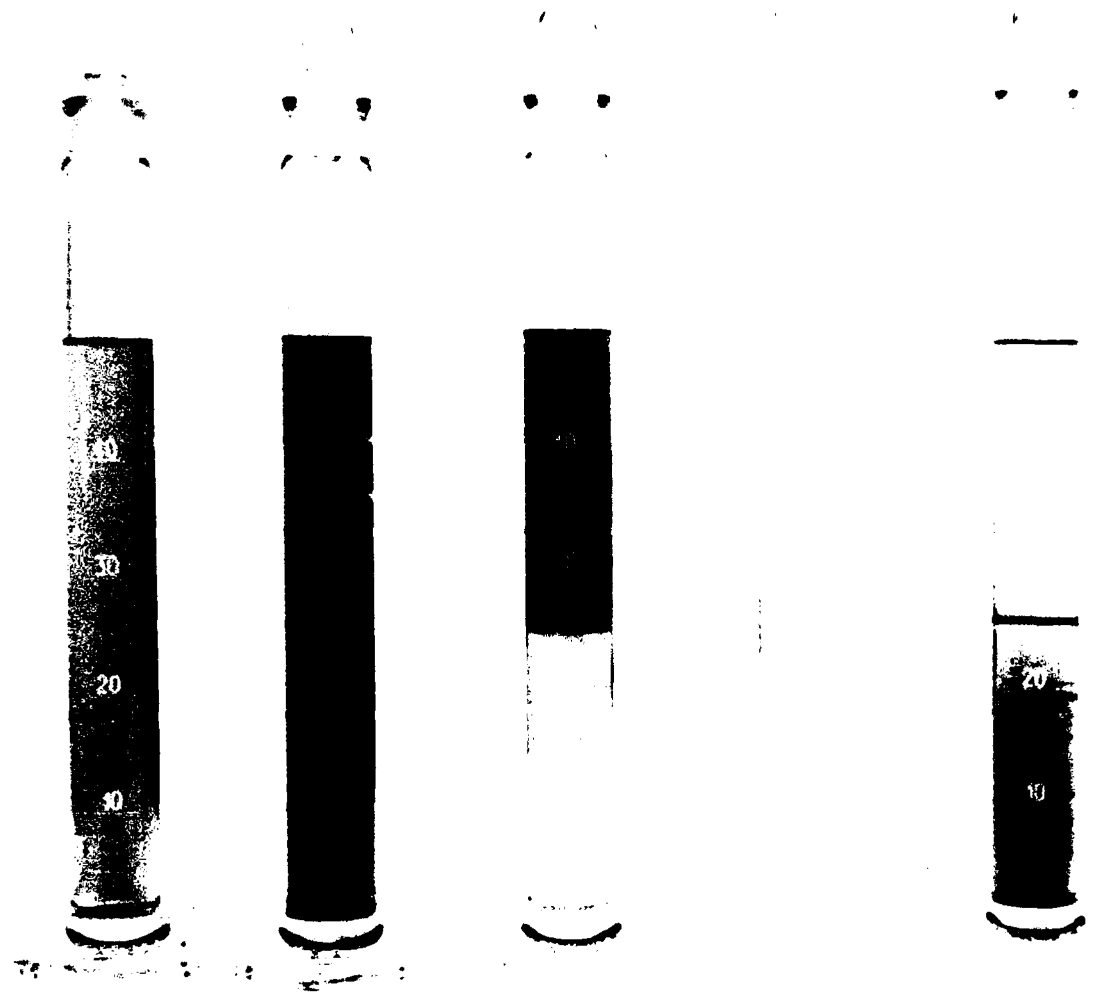

Figure 2. The Phase Inversion Phenomenon.

3. Wheel Cylinders and Plexiglass Windows.

a. Apparatus. For the purpose of visually observing the mixing, a wheel cylinder from a 5-ton vehicle was equipped with end plates made of plexiglass and bolted in place to provide a fluid seal. The spring, pistons, and cups were removed for viewing, and the dust boots were trimmed so that the window diameter was approximately 1½ in. for easy viewing of the process. A lamp was placed at the rear of the assembly so that the interior of the cylinder was illuminated.

b. Experiments. The wheel cylinder was charged with polyglycol, and a series of experiments was performed for the purpose of determining the feasibility of the method and ascertaining if effective mixing could be accomplished. The degree of mixing, aeration of the fluids, and phase behavior were observed visually.

4. Mock-up of a Brake System.

a. Apparatus. A system of six-wheel cylinders and a master cylinder was constructed and they were connected with ¼-in. copper tubing. The wheel cylinders were bolted to a bracket so that they could be bled properly.

b. Experiments. Systems of long and short lines were used, and different flushing volumes of the density modifier were used to develop a method for eventual use in a vehicle.

5. Caliper Experiments.

a. Apparatus. A caliper from a 1978 Dodge van (left front) was attached to the master cylinder with a 3-ft line, and spacers were clamped into the caliper to fix the internal volume at 90 ml.

6. Used Wheel Cylinders. A used wheel cylinder from a 5-ton truck was connected to the master cylinder, and flushing experiments were conducted to determine the effect of the sludge and the extent of sludge removal in the process.

7. Administrative Vehicle Test.

a. Apparatus. This vehicle was selected because it had both wheel cylinders and calipers and because it had over 100,000 mi on it so it could be expected to be a worst-case test.

b. Test. A proposed procedure based on previous experiments was used (Appendix D), and the vehicle was converted. This procedure involved purging the system with air, flushing the two rear wheels simultaneously, and then flushing each caliper with air and the 2-EH twice each. The vehicle was then pressure-bled with BFS. After brake pedal firmness was checked, the wheel cylinders and calipers were removed, the fluid collected (and analyzed), and the vehicle reassembled. Since this procedure was experimental, the system was changed back to polyglycol fluid.

8. Demonstration of the Method. A description of the vehicles used is given in Appendix E. The demonstration consisted of converting a 2½-ton vehicle and a ¼-ton vehicle (a 5-ton and an M880 were also available, had it been necessary). A second 2½-ton vehicle was converted on a dry-run basis prior to the demonstration to attempt to address any potential problems which might occur during the demonstration.

IV. RESULTS OF TESTS

9. Air Flushing. After the wheel cylinder was filled with water and air applied (pressure unknown), a mist occurred at the threads of the open bleeder valve. These are straight threads and do not provide a fluid seal. However, due to the lower viscosity of the water as opposed to polyglycols and silicones, this problem did not occur with these fluids. The results using three flushing techniques are given in Table 1. With air flushing and vacuum pulling, the residual glycol levels are very high.

Table 1. Results of Air Flushing (5-Ton Wheel Cylinder)

	Cylinder Volume (ml)	Residual Glycol (ml)	Remaining Glycol (%)
Air Flush (Into Inlet)	85	51	37
Reverse Flush (Into Bleeder)	85	8	9.4
Vacuum (From Bleeder)	85	49	57.6

10. Solvent Addition. This experiment demonstrated the density inversion process. The 2-EH, a density modifier, reduces the density of the polyglycol to such an extent and in such a manner that upon addition of the silicone, two layers form with the silicone on the bottom. This phenomenon provides a basis for effective glycol replacement, the mechanism of which is displacement as opposed to dilution. A critical element in this approach is to achieve complete mixing of the density modifier with the polyglycol fluid especially at the lower part of the wheel cylinder (Figure 1). Since the density of the 2-EH is less than that of the polyglycol, it was assumed that mixing (of the density modifier with the polyglycol) would involve the same problems as with the polyglycol/BFS system, specifically, at the lower part of the wheel cylinders.

A diffusion controlled mixing method was thought to be insufficient based on the relative densities and viscosities and on the test tube observation that mixing is not immediate without agitation (and that it would not be feasible to agitate a vehicle positioned for conversion). Thus, air purging was used.

11. Wheel Cylinders and Plexiglass Windows (5-Ton Wheel Cylinder). The results of these experiments are outlined in Table 2. The air flushing method for mixing was found to be effective in this system if the system is filled twice with the density modifier and then purged with air. Sufficient 2-EH remains in the wheel cylinder to reduce the density of the polyglycol so that it is less dense than that of the silicone. No visible trace of the polyglycol remained in the system. These experiments established the feasibility of the method and determined that air flow was the method of choice for mixing the 2-EH/polyglycol in the wheel cylinder. In addition, when the silicone was added to a wheel cylinder containing polyglycol which had been blown out with air, the aeration of the glycol was substantial and would be expected to give spongy brakes.

12. Mock-up of a Brake System. The results of these tests are given in Table 3, and a simultaneous flushing technique was found to be feasible using this system.

13. Caliper Experiments. This experiment demonstrated that a single flushing was not sufficient for disc brake calipers.

14. Used Wheel Cylinders. A used wheel cylinder from a 5-ton truck was flushed with 400 ml of 2-EH and emptied into a flask. After the addition of BFS (500 ml), the upper layer contained the particles of sludge broken loose by the air and the glycol/2-EH mixture. After the flask was shaken, a single layer formed and the sludge, to some extent, appeared to break up the two-phase system when agitated.

Table 2. Results of Experiments with Wheel Cylinders Equipped with Plexiglass

Experiment	Extent of Mixing	Aeration of Contents	BFS on Top/Bottom	BFS Aerated	Mixing BFS/Polyglycol
1. Addition of 2-EH by Syringe	No Apprecia-ble Mixing	—	—	—	—
2. Air Purge of Polyglycol; Then, Gravity Addition of Hexanol	No Apprecia-ble Mixing	Aerated Polyglycol Layer	—	—	—
3. Air Purge Before and After Hexanol Addition	Complete Mixing	Aerated Polyglycol Layer	BFS on Top (Aerated PG on Bottom	Not Aerated	None
4. Air Purge Before and After Hexanol Addition, 2 Cycles	Complete Mixing	Aerated Polyglycol Layer	BFS on Bottom	Not Aerated	None
5. Pressure Flushing with 2-EH	Incomplete Mix-ing at Lower Part of Cylinder	—	—	—	—

NOTE: The wheel cylinder in each case was bled with polyglycol fluid, and the respective experiments performed. Hexanol was used for experiments 2 through 4, but was ultimately rejected due to its relatively lower boiling and higher melting points. In the silicone brake fluid addition steps, the silicone was added by gravity or by the syringe (not pressure bleeding conditions).

Table 3. Results of Mock-up Experiments

Experiment	Procedure	Residual Alcohol (%)	Residual Polyglycol
1. Short Lines	3 flushes	—	Traces
2. Long Lines	3 flushes	0.96—1.49	No Trace
3. Long Lines	2 flushes	1.19—6.30	No Trace
4. Long Lines	1 flush	1.47—4.29	Traces

NOTE: Six wheel cylinders were mounted using either long or short fluid lines and were flush/filled using a solvent method. All wheel cylinders were flushed simultaneously.

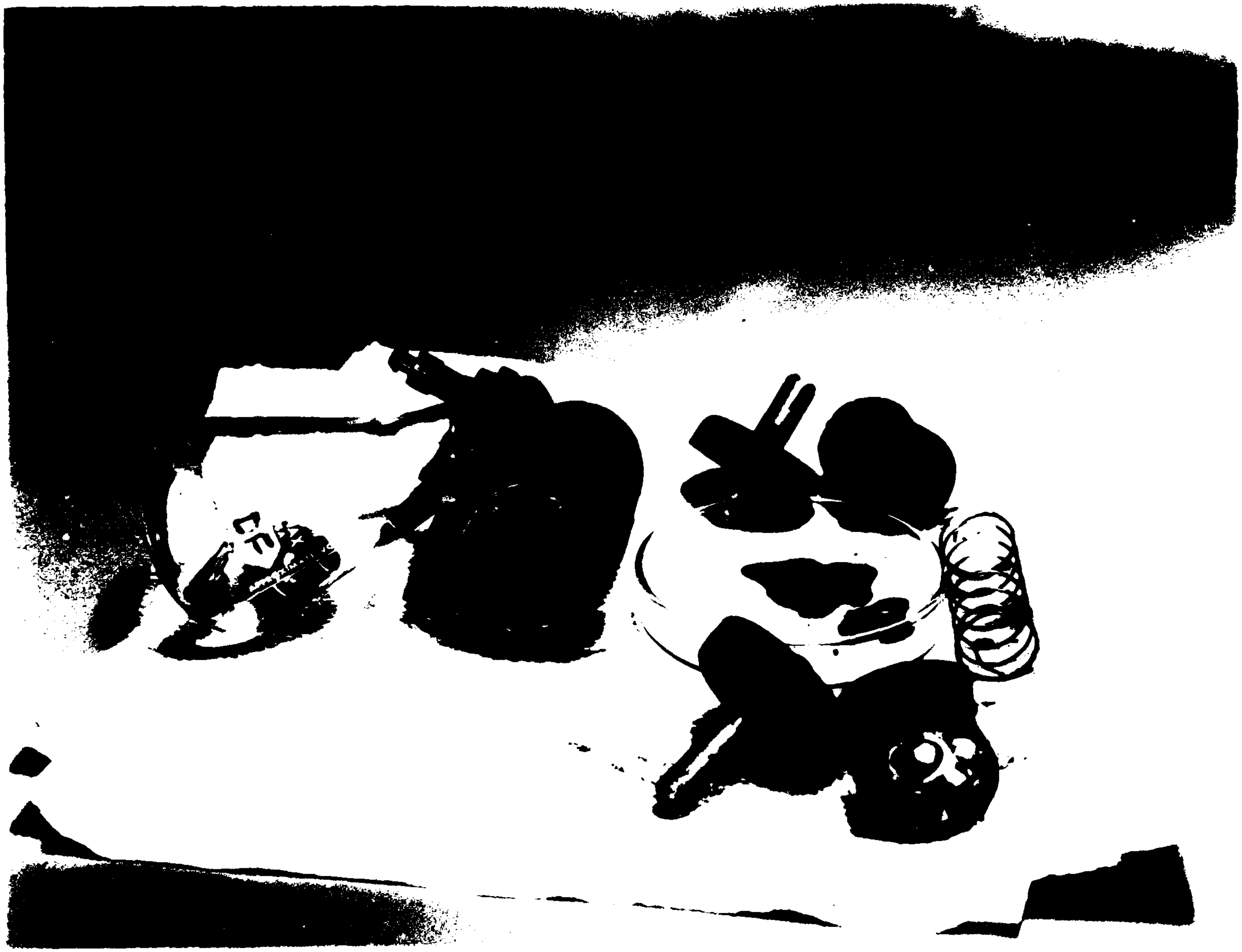

Figure 3. Driver Front Wheel Cylinder from HO11.

15. Conversion of an Administrative Vehicle. Table 4 gives the results of the analysis of the fluid from each wheel cylinder and caliper as well as the fluid used. Clearly, the method was found to be an effective method for replacement of glycol brake fluids by BFS. The fluid in the vehicle after conversion passed the tests for MIL-B-46176.

16. Demonstration of the Method. The results of the analysis of the fluid from the 2½-ton vehicle used in the dry run test are given in Table 5. This vehicle was selected for disassembly because when the system was purged with air initially, a fluid with a distinctive red color was observed. This fluid could be a commercial brake fluid, automatic transmission fluid, or MIL-H-6083. If it was either hydraulic fluid, then it would present problems for the operation of the vehicle (due to rubber swell). The method would work in any case, but excessive rubber swell could cause a dangerous situation. No indication of this was observed upon disassembly of the wheel cylinder.

Additional sludge (Figure 3) from the walls of the wheel cylinder broke loose and drained out after removal of the dust boots, cups, pistons, and spring. The observation of a measurable amount of glycol in one of the wheel cylinders is probably due to ent[illegible] of the polyglycol fluid by the sludge, which could render it inaccessible to the solvent. In general, the fluids are clear and virtually no trace of the polyglycol remains. Although the method does remove some sludge, there is a substantial amount remaining in the wheel cylinders adhering to the walls.

Driver front wheel cylinder from HQ11 (Figure 3). The silicone fluid which was poured into the flask prior to disassembly shows a single layer. The glass dish contains some of the sludge which was broken loose when the wheel cylinder was opened. The interior of the cylinder shows additional sludge as do the pistons.

17. Miscellaneous Testing. Table 6 lists a summary of additional testing and evaluation of the use of 2-EH as the flush fluid.[11] The parameters shown in the property column could have a critical effect on the performance of the silicone fluid after conversion. For example, if an excessive residual amount of 2-EH remains in the system, excessive rubber swell could occur. Also, if an alternate fluid were used which has a higher moisture absorption, then a larger amount of water could be absorbed, and the problems associated with the water would occur. The elastomer swell is the most critical parameter, and the method has been designed to preclude, as much as possible, the occurrence of excessive amounts of 2-EH after conversion.

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[11] *Elastomer Swell Data* provided by: C. Jordan, STEAP.

Table 4. Results of Solvent-Assisted Flush/Filling of an Administrative Truck

Order of Bleeding	Wheel	Component Capability (ml)	Volume of Alcohol Flushed Through Component[1] (ml)	Volume of Fluid Collected During Bleeding (ml)	Residual Polyglycol (Visual)[2]	Vapor Lock Temperature (%F)
1	Passenger Rear Wheel Cylinder	7.4	145	250	N.T.	435
2	Driver Rear Wheel Cylinder	9.5	145	130	N.T.	453
3	Passenger Caliper	60	870	285	N.T.	490
4	Driver Front Caliper	61	580	2 5	N.T.	480

[1]The two rear wheel cylinders were *flushed simultaneously with 290 ml.*

[2]No trace of polyglycol could be detected by visual examination.

Table 5. Fluid Analysis of Wheel Cylinders from HQ11

Wheel Cylinder	Residual 2-EH (%) 200 ml	Residual 2-EH (%) 230 ml	Polyglycol
PR1	2.3	0.8	NT
PR2	0.95	0.7	2%
PF	1.6	0.6	T
DF	1.0	0.8	NT
DR1	2.5	0.9	T
DR2	1.7	0.95	T

NOTES: This vehicle was converted during the dry run.

DF = driver front
PR2 = passenger side, mid wheel
T = trace
NTP = no trace

A sample of 28 ml was taken from each wheel cylinder after conversion for analysis. This represents the residual 2-EH level in the vehicle after 200 ml was collected at the bleeder. The values for the contents of the wheel cylinders are also given in the 230 ml column. The method now recommends *250 ml from each wheel cylinder*. The levels were measured by gas chromatography.

The front wheels of this vehicle contained a fluid with a distinct red color (possibly, automatic transmission fluid, hydraulic fluid MIL-H-6083, or commercially procured brake fluid).

Table 6. Critical Properties of Flush/Fluid[1]

Property	2-Ethyl Hexanol (2-EH)	MIL-B-46176 Parameter	Contamination Level Tested (2-EH/BFS)	Value	Result of Test With Silicone Brake Fluid *Containing* Residual 2-EH
1. Boiling point	184.8°C	Vapor Lock Temperature	2'	450°F	Pass
2. Freezing Point	-76°C	Pass at -65°F	—	—	Pass
3. Flash Point	185°F (open cup)	400°F	—	—	Pass[2]
4. Elastomer Compatibility	—	As Stated	2%	—	Pass
Stroking Performance	—	As Stated	3%	—	Pass
5. Density	.8323	—	—	—	Pass
6. Moisture Absorption	2.7%	Wet Vapor Lock Temperature After Humidification Test (0.1% water, KF)	5%	360°F	Pass
7. Toxicity	Slight	—	—	—	Pass
8. Cost	$3.15/gal (bulk rate)	$15-17/gal	—	—	Pass

[1]Comparison to MIL-B-46176 (Brake Fluid, Silicone) specification requirement and results of testing of the effect of residual 2-Ethyl Hexanol levels.

[2]The minimum flash point for VV-B-680 fluids is 179.6°F (current polyglycol brake fluids).

V. CONCLUSIONS

It is concluded that: the use of a density modifier as an alternate mechanism for brake fluid replacement has been developed and has been tested under laboratory conditions as well as with military vehicles. The density modifier (2-EH) generates a binary phase system which exhibits an isopycnic tie line, and sufficient 2-EH is used to pass this tie line so that a reversal of the phases occurs (Figure 4). This approach has been found to be highly effective at polyglycol replacement but the mixing of the density modifier must be accomplished by the use of low pressure air flow. This mechanism of fluid replacement is very effective. Further testing has established suitable procedures for the conversion of the vehicles tested which included techniques to insure minimal residual contamination of the silicone with the 2-EH. The fluid remaining in the system under these conditions has a high vapor-lock temperature, is functional at low temperatures, and is not hygroscopic.

Comparison of flush/fill and solvent-assisted flush/fill methods (Figure 4). A straight flush/fill method results in the situation on the lower left side where the wheel cylinders and calipers have residual polyglycol. The upper center and right side of the diagram illustrate the solvent-assisted method. The system is purged of the bulk of the polyglycol with air (master cylinder, lines, and, to some degree, the wheel cylinders). The solvent (2-EH) is added at the master cylinder and flushed through the system with air. Continued application of the air for 60 s gives enough mixing to reduce the density of the remaining polyglycol sufficiently so that upon addition of the BFS, the situation in the lower right wheel cylinder occurs (and subsequently after bleeding, the lower center situation exists).

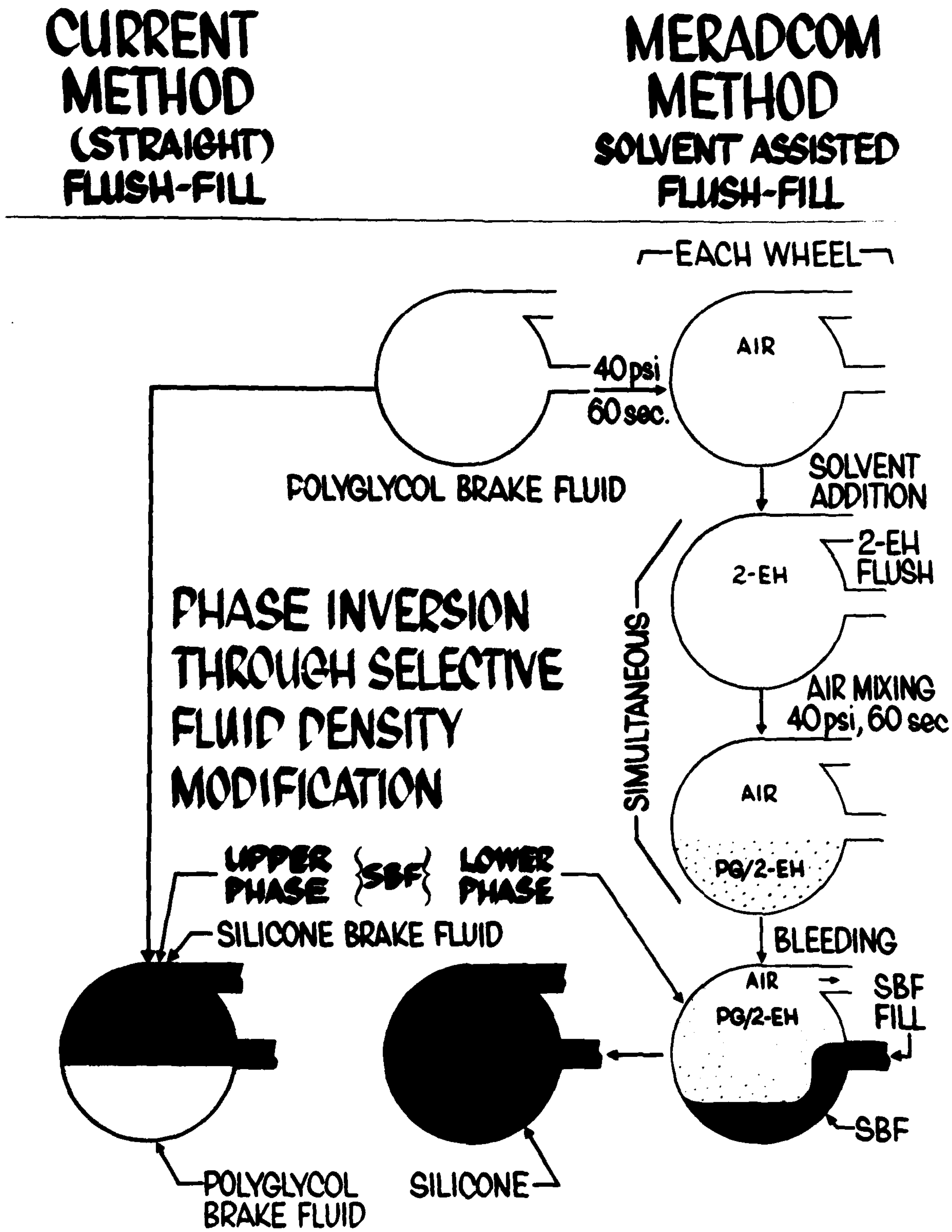

Figure 4. Comparison of Flush/Fill and Solvent Assisted Flush/Fill Methods

APPENDIX A

WIPE-AND-CLEAN PROCEDURE FOR RETORFITTING A CONVENTIONAL AUTOMOTIVE BRAKE SYSTEM WITH MIL-B-46176 BRAKE FLUID, SILICONE (BFS)

1. Clean filler/bleeder thoroughly with alcohol and dry completely before it is used with silicone brake fluid. After the unit has been cleaned once, it will never need recleaning.

2. Drain out existing brake fluid (VV-B-680, MIL-H-13910, or MIL-P-46046).

3. Disconnect brake lines from master cylinder and remove master cylinder. Disassemble master cylinder, inspect, and replace if necessary; if no signs of corrosion or rubber deterioration, clean thoroughly and reassemble. Repack with MIL-B-46176 Silicone Brake Fluid,

4. Disconnect brake lines or hoses from wheel cylinders and allow lines to drain.

5. Remount master cylinder and reconnect master cylinder brake lines. Plug brake lines of hoses with a female cap or appropriate size to facilitate flushing of the lines.

6. Fill the master cylinder with MIL-B-46176 Silicone Brake Fluid using the filler/bleeder unit. Flush lines with silicone brake fluid until old fluid is removed (about 1 pt). New fluid is a bluish/purple color and the existing fluids are a light amber color.

7. Open and inspect wheel cylinders. If there is evidence of corrosion, excessive wear, or deterioration of the rubber components, replace cylinder. If the cylinder is in good condition, clean thoroughly with a clean rag to remove all traces of the old fluid.

8. Reassemble or remount wheel cylinders as necessary and reconnect brake lines or hoses.

9. Fill and bleed with silicone brake fluid MIL-B-46176 according to established procedures.

APPENDIX B

PROPERTIES OF 2-ETHYL HEXANOL

* Ethyl-2-hexanol, 2-ethyl hexanol, 2-ethylhexyl alcohol, octyl alcohol,iso octanol

CH_3-$(CH_2)_3CHC_2H_5CH_2OH$

Molecular Weight	130.22
Boiling Point	184.8 °C
Freezing Point	-76 °
Density	0.8323
Vapor Pressure at 20 °C (m bar)	0.5
Water Absorption (wt. %)	
Flash Point	74 ° to 80 ° C (178 °F)
Ignition Temperature	250 °C (482 °F)

Derivation: (a) Oxo process, from propylene and synthesis gas. Petrochemical route (95%). (b) Aldolization of acetaldehyde or butyraldehyde, followed by hydrogenation. Coal route.

Grade: Technical.

User: Plasticizers defoaming agent, wetting agent, organic synthesis, solvent mixtures for nitrocellulose, paints, lacquers, baking finishes, penetrant for mercerizing cotton, textile finishing compounds, inks, rubber, paper, lubricants, photography, drycleaning.

World Capacities: 1.616 M metric tons/y (current).

*Cornils, D. and Mullen, A., 2-EH: *What You Should Know*, *Hydrocarbon Processing*, November 1980 p. 93.

APPENDIX C

GAS CHROMATOGRAPHIC PROCEDURE FOR THE ANALYSIS OF 2-EH IN BFS

Conditions:

Column: Carbowax 20M (6 ft x 1/8 in.)
Flow Rate: 30 ml/min (nitrogen)
Temperature 1: 100 °C
Rate: 10 °C/min
Temperature 2: 350 °C
Injector: 250 °C
Flame Ionization Detector: 300 °C
Attenuation: 13
Slope Sensitivity: 0.50
Area Rejection: 1.00
Retention Time (2-EH): 1.93
Internal Standard: Decane

APPENDIX D

CONVERSION PROCEDURES FOR VEHICLES

Improved BFS conversion methods for jeep, M-880 (administrative), 2½-ton and 5-ton vehicles. For these procedures which involve fluids under pressure, eye protection should be worn.

Material Needed:
1. Source of 40 $lb/in.^2$ air.
2. Barrel or other vessel for collection of fluids.
3. Vent hose to exterior (automotive exhaust tubing).
4. 2-ethyl hexanol.

M-880 (Administrative)

1. Attach adapter to master cylinder and apply 40 $lb/in.^2$ (air pressure).

2. Attach tubing (connected to collection receptacle) to both rear bleeder valves and open them (check that flow is occurring).

3. Allow air to pass through the system until the bulk of the fluid is gone (no more than 60 s).

4. Fill master cylinder with 2-EH and apply air pressure for 60 s.

5. Close both rear bleeder valves.

6. Attach tubing to caliper bleeder valves.

7. Open passenger side caliper and allow air to pass until the bulk of the fluid is gone. (No more than 60 s; the rod on the connector block must be depressed).

8. Fill master cylinder with 2-EH and apply air for 60 s.

9. Repeat step 8 and close the bleeder valve.

10. Repeat steps 7, 8, and 9 for the driver side caliper.

11. Pressure bleed the system with BFS in the following order, and collect at least the following amounts of fluid (making sure that no more air comes out the bleeder valves). The rod on the connector block must be depressed while bleeding the calipers.

a. Passenger Rear 400 ml

b. Driver Rear 250 ml

c. Passenger Caliper 400 ml

d. Driver Caliper 400 ml

12. The connector block on M-880 vehicles is attached to the inside of the frame underneath the master cylinder and is accessible only from underneath the vehicle. Administrative vehicles will likely be different according to manufacturer. The administrative vehicle previously converted had a connector block attached to the firewall accessible under the hood.

¼-Ton (M-151)

1. Attach adapter to master cylinder and apply 40 $lb/in.^2$ of air pressure.

2. Attach tubing (connected to receptacle) to both rear valves and open valve. Check that flow is occurring.

3. Allow air to pass through the system until the bulk of the fluid is gone (no more than 60 s).

4. Repeat steps 2 and 3 for the front wheels.

5. Fill master cylinder with 2-EH and apply air pressure.

6. Attach tubing to bleeder valves and open.

7. Allow air to pass through the system for 60 s and close bleeder valves.

8. Repeat steps 5, 6, and 7 for the two remaining wheels.

9. Pressure bleed the system with BFS in the following order, and collect at least the following amount of fluid (make sure that no more air comes out of the bleeder valves).

a. Passenger Rear 400 ml

b. Driver Rear 200 ml

c. Passenger Front 200 ml

d. Driver Front 200 ml

2½-Ton

1. Attach adapter to master cylinder and apply 40 lb/in.^{2} (air pressure).

2. Attach tubing (connected to collection receptacle) to bleeder valve and open valve. Check that flow is occurring.

3. Allow air to pass through the system until the bulk of the fluid is gone (no more than 60 s) and close the valve.

4. Repeat steps 2 and 3 for each wheel and the air over-hydraulic unit. The 5-ton vehicles have two bleeder valves on the air over-hydraulic unit.

5. Fill the master cylinder with 2-EH and apply air pressure.

6. Attach tubing to bleeder valve and open.

7. Allow air to pass through the system for 60 s and close the bleeder valve.

8. Repeat steps 5, 6, and 7 for each wheel and the air over-hydraulic unit.

9. Pressure bleed the system with BFS in the following order, and collect at least the following amounts of fluid (make sure that no more air comes out of the bleeder valve).

a. Air Hydraulic Pack	400 ml
b. Passenger Rear	400 ml
c. Driver Rear	250 ml
d. Passenger Middle	250 ml
e. Driver Middle	250 ml
f. Passenger Front	250 ml
g. Driver Front	250 ml

APPENDIX E

VEHICLES USED IN THIS STUDY

1. Truck Maintenance, 1976 International Harvester, USA No. CB5989. NSN: 2320-00-287-1991; Mileage: 113,046. The wheel cylinder (passenger rear) was badly corroded.

2. 5-ton vehicle, bumper No. HQ11, 310TAACOM, 55MMC, Mileage 9081.

5-ton vehicle, bumper No. HQ41, 310TAA, 343DE, door 4L6711, Mileage 10007.

¼-ton vehicle, MERADCOM TV75, U.S. Army 02E19672, M-880, U.S. Army N60KXZ.

Figure [illegible] of the Model

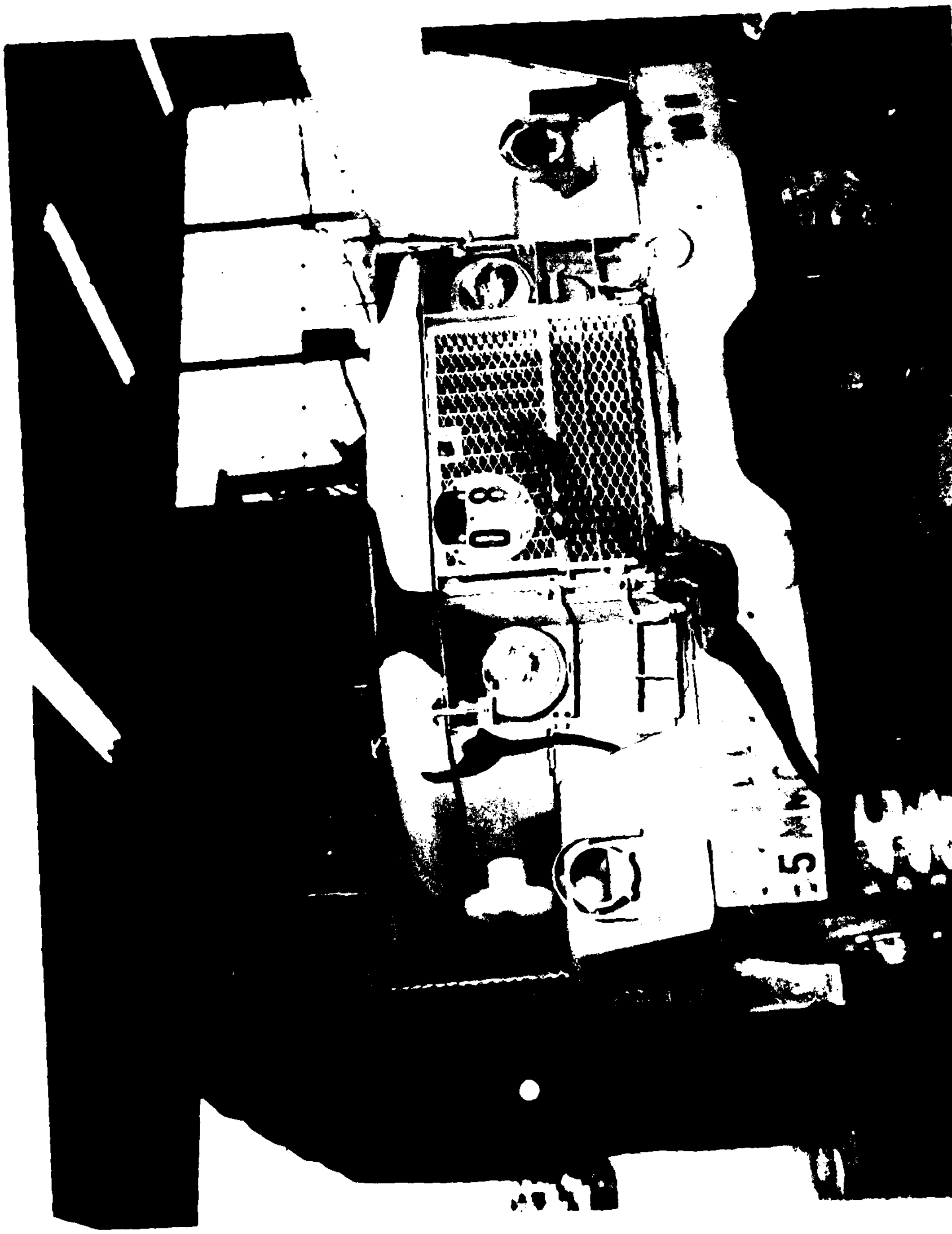

Figure E-2. HQ11, a 2½-Ton Vehicle Used in the Dry Run of the Method.

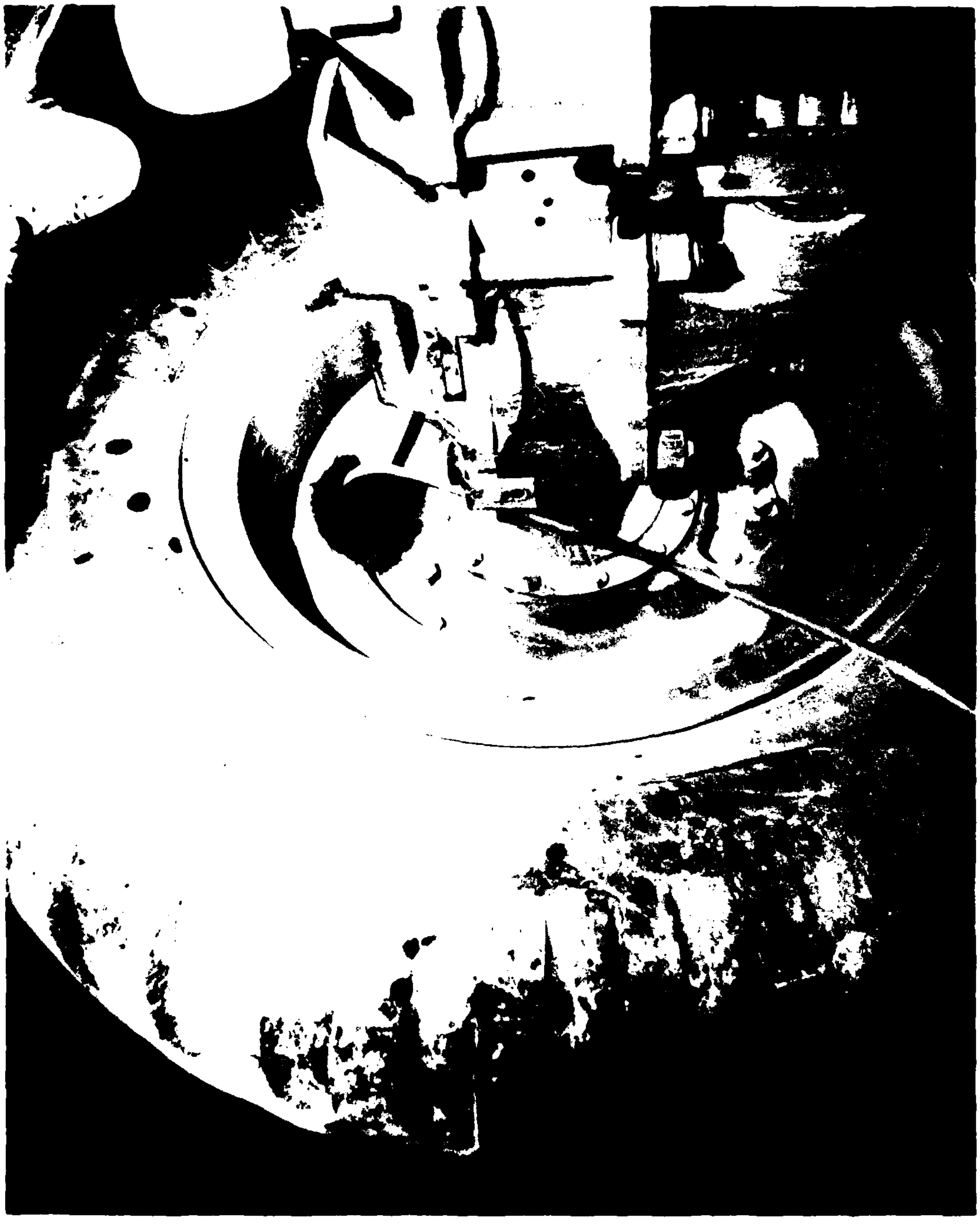

Figure E-3. Attachment of Vent Hose to the Bleeder Valve.

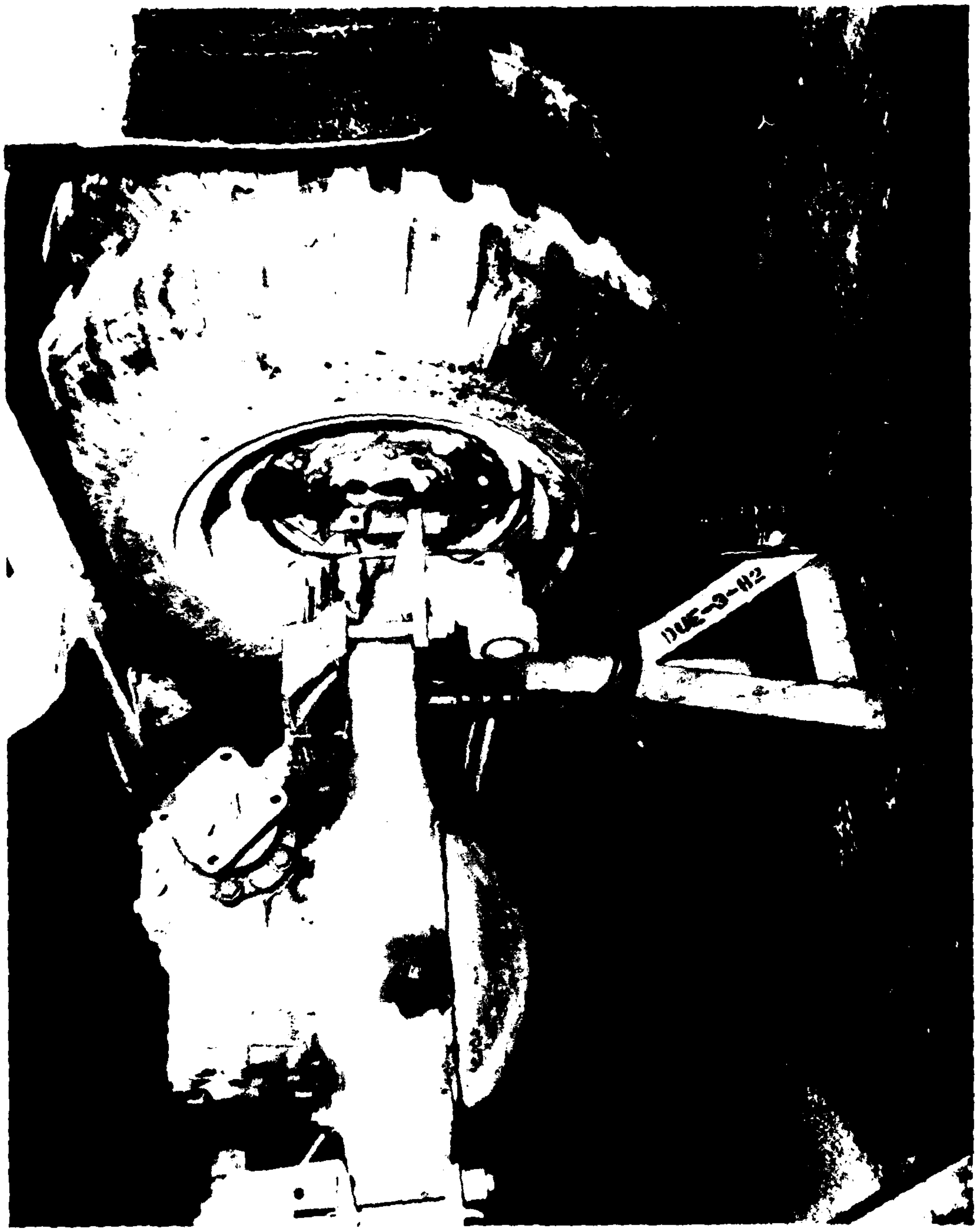

Figure E-4. The Bleeding Process.

Figure E-5. Attachment of Pressure Bleeding Apparatus to Master Cylinder.

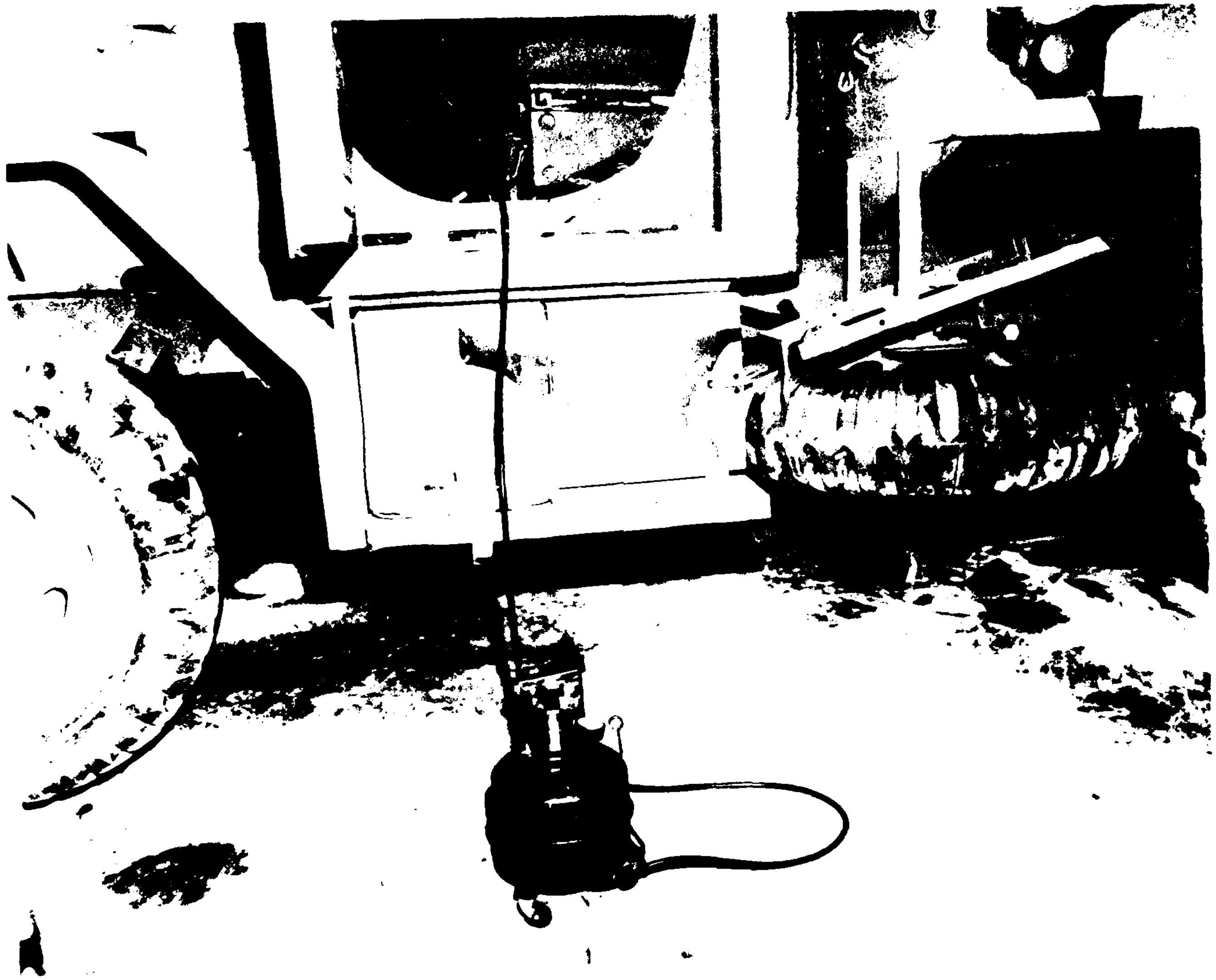

Figure E-6. Pressure Pot Attached to Master Cylinder During Bleeding Process.

Figure E-7. Regulator Used to Reduce Line Pressure to 40 lb/in.^{2}.

APPENDIX F

LARGE-SCALE OPERATIONS

There are two approaches to large-scale conversion, on-site, where the vehicles are not moved for the conversion but are converted where they stand and in shop where each vehicle is brought into the shop, on an assembly line basis to be converted.

For the on-site conversion, each vehicle could be equipped with the conversion apparatus, be driven around to each individual vehicle, and be converted. The vehicle would require sufficient room for waste drums, a compressor (or compressed air cylinder), and the fluids required. The adapters and tubing needed would not require any significant space. This could be a one-person operation, but would be more efficient if two persons were used. One person could be going from vehicle to vehicle performing the site preparation, loosening bleeders and master cylinder caps and vents.

For large-scale conversion in a shop facility, the hardware would be the same but located centrally. The driver would drive the vehicles in and prepare them for conversion (by opening valves and attaching adapters, etc.). The vehicles would be prepared, driven into the shop, converted, driven out, and test driven back to the point of origin. Again, this could be a one-person operation, but two persons would be more efficient.

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